AFCRL-70-0209
APRIL 1970
PHYSICAL SCIENCES RESEARCH PAPERS, NO. 416

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

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United States Air Force

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AERONOMY LABORATORY PROJECT 6687

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This research was supported by the Defense Atomic Support Agency.

This paper was presented at the Third Aeronomy Conference held at the University of Illinois, Urbana, Illinois, on 23-26 September 1968, and was published in Meteorological and Chemical Factors in D-Region Aeronomy-Record of the Third Aeronomy Conference (C. F. Sechrist, Jr., Editor), 1 April 1969.

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Abstract

Positive ion composition measurements in the D and E regions were performed on three rocket flights during the 1966 solar eclipse program conducted at Cassino, Brazil. The E region results showed that, at totality, NO^+ and O_2^+ decreased in density while the ratio NO^+/O_2^+ increased. Long-lived meteoric ions appeared to be unaffected during the short period of the eclipse. A submerged layer of meteoric ions became prominent at totality when the molecular ion densities were smallest and produced a sporadic E layer. The D region results indicated that the decay in the water cluster ions at totality was probably less than a factor of four in the vicinity of 80 km. This work represents part of a continuing Air Force program to study lower ionospheric processes which affect communications.

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Positive Ion Composition Measurements in the Lower Ionosphere During the 12 November 1966 Solar Eclipse

1. INTRODUCTION

Cryogenically-pumped quadrupole-mass spectrometers were included as part of the scientific payloads on four Defense Atomic Support Agency rockets launched from Cassino, Brazil to study the D and E regions of the ionosphere during a total solar eclipse. Three of these instruments were successful. Because the gyro aspect data are not yet available, the results are presented in terms of the currents measured at the mass peaks versus altitude, and all current modulations were smoothed out by eye. A certification rocket launched one week before the eclipse provided background ionospheric measurements which showed the Brazilian daytime ionosphere to be similar to that over Eglin, Florida. The water cluster ions, 19^+, 37^+ and 55^+, $(H^+ \cdot (H_2O)_n)$ dominated the ion composition below 82 kilometers and disappeared completely above 85 km. The drastic transition in ionospheric composition near 83 km, marked by the disappearance of the water cluster ions and the simultaneous appearance of metal-atomic ions, seems to be a consistent feature of the earth's ionosphere. Metallic ions, mostly iron and magnesium, were measured from 83 to 106 km and showed a layer near 93 km with a peak density of about 10 percent of the total ionization. NO^+ and O_2^+ were about equally abundant and were the major constituents above 83 km. During the eclipse, the results obtained when the sun was 80 percent obscured from rocket D-4, were

(Received for publication 9 March 1970).

found to be somewhat similar to those from the certification rocket except that an additional narrow metal ion layer, composed mostly of magnesium and iron, was found near 105 km. At totality, the results from rocket D-11 indicated that both NO^+ and O_2^+ decreased in density while the ratio NO^+/O_2^+ increased. The metallic ions appeared to be unaffected by the solar eclipse. The decay, if any, of the 37^+ ion at totality was probably less than a factor of four in the vicinity of 80 km.

2 DATA

In addition to the mass spectrometer, the Nike Hydac payload contained a retarding potential analyzer, an impedance probe, a Langmuir probe, a spherical ion trap, a solar x-ray detector, and a lyman-alpha detector. All the payloads contained an attitude control system (ACS) which was programmed after separation from the rocket motor near 60 km, to maintain the payload at zero angle of attack over its trajectory. Only the results of the mass spectrometer experiments are discussed here. Positive-ion composition measurements were made with cryogenically-pumped quadrupole-mass spectrometers. In all cases, the mass spectra were scanned from 10 to 64 amu and the total ion current for masses above 49 amu were measured, all in a two-second period. Three figures were plotted (see Figures 1 through 3) showing only the major positive ions detected on the certification, D-4, and D-11 rockets. These plots are in terms of the currents measured at the mass spectral peak versus altitude. The major ions measured and our identifications are 19^+ (H_3O^+), 37^+ ($H_5O_2^+$), 55^+ ($H_7O_3^+$), 30^+ (NO^+), 32^+ (O_2^+), 24^+ (Mg^+) and 56^+ (Fe^+). Other mass peaks, generally much smaller in relative concentrations, were detected. Some of these were identified as sodium, aluminum, nickel, and calcium ions. We believe the maximum altitude error in the trajectory data is ±2 km. No attempt was made to correct or to normalize the current profiles for the particular instrument sensitivity, vehicle speed, and vehicle aspect since the aspect data were not available. (For information, the ratios of the instrument sensitivities were certification :D-4:D-11 = 1:1.3:1.7, which means, for example, the D-11 instrument was 1.7 times more sensitive that the certification instrument, etc.). Thus one cannot consider changes in the current values for a particular constituent from one rocket flight to another, as being indicative of the changes in the densities of that constituent. For any single flight, more significance can be attached to the relative currents at a particular altitude as being representative of the relative composition, but keeping in mind the particular problems and uncertainties discussed below for each set of results.

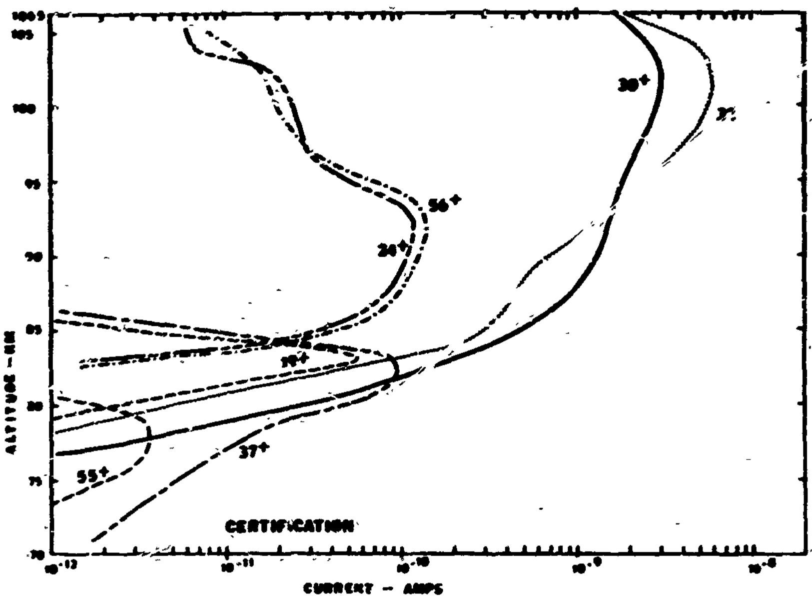

Figure 1. Major Positive Ions, 5 November 1966, 1155 L. T., Cassino, Brazil, Nike Hydac

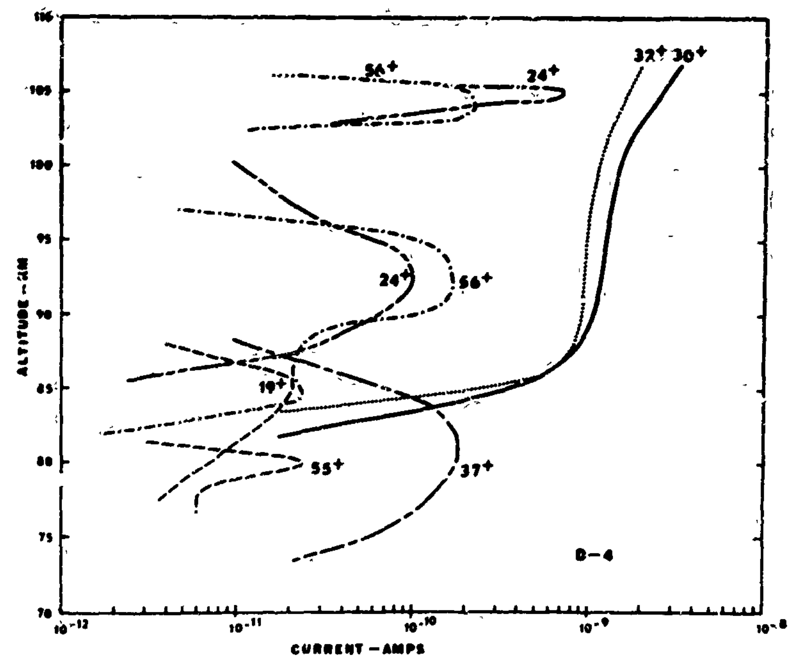

Figure 2. Solar Eclipse - Major Positive Ions at 80% Obscuration, 12 November 1966, 1154 L. T., Cassino, Brazil, Nike Hydac

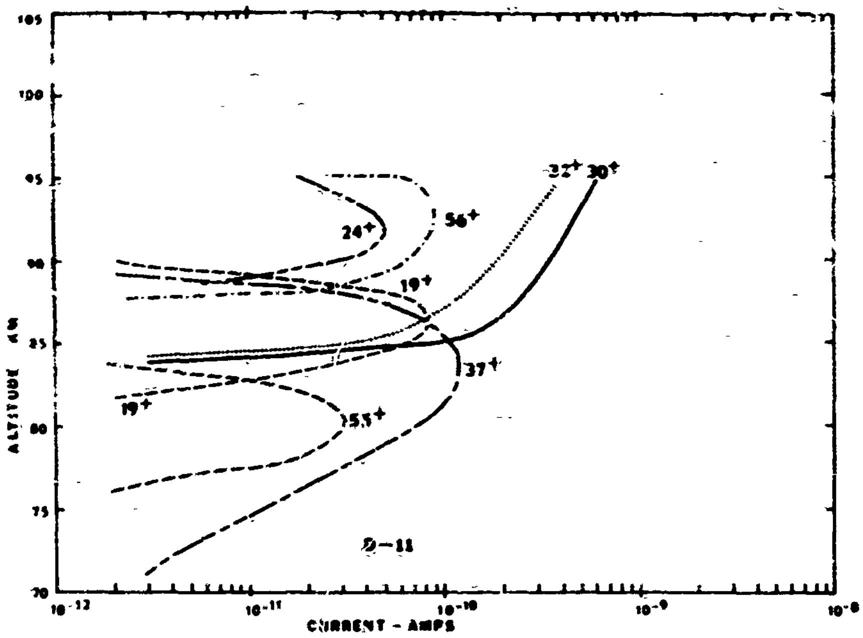

Figure 3. Solar Eclipse - Major Positive Ions During Totality, 12 November 1966, 1209 L. T., Cassino, Brazil, Nike Hydac

3. CERTIFICATION ROCKET

This rocket was launched at 11:55:21 L. T. on 5 November 1966 to obtain background measurements. The vehicle developed severe coning because the payload did not separate from the Hydac motor, rendering the attitude control system ineffective. Only the ascent data were used for the plot. The most serious modulations were in the 30^+ and 32^+ currents above 93 km; the smoothed curves for these constituents deviate about a maximum of a factor of two from the measured values. For all the other constituents and below 93 km for 30^+ and 32^+, the smoothed current profiles are well within a factor of two of the measured values.

4. D-1 ROCKET

This rocket was launched at 11:54 L. T. on 12 November 1966 so that the rocket was ascending at 90 km when the sun was 80 percent obscured. Again the payload did not separate from the Hydac motor and the vehicle behaved poorly. The best mass spectral data were obtained near peak on upleg and on descent.

Only the descent data were used for the plot. The current modulations in 39^+ and 32^+ above 90 km were sinusoidal in nature, showing about 2 cycles from 90 to 107 km with amplitudes plus or minus about a factor of two about a mean value. The curves shown in the plot are these mean curves. The smoothed curves for the other constituents are generally within 40 percent of the measured values.

5. D-11 ROCKET

This rocket was launched at 12:08:37 L. T. on 12 November 1966 so that the rocket was ascending at 90 km during totality. The payload separated from the rocket motor and was stabilized by the ACS, so that the current modulations were not as serious as on the certification and D-4 rockets. The plotted current profiles are the results of smoothing a superposition of both the ascent and descent measurements. All the current profiles are generally well within ±50 percent of the measured values.

6. DISCUSSION

The results of the certification rocket showed the daytime Brazilian ionosphere to be quite similar to that measured in the northern hemisphere. Below 82 km water cluster ions (hydrated protons) dominated the composition. These ions disappeared completely near the mesopause and were absent above 87 km, but reappeared on rocket descent below 87 km.

Another typical feature of the lower ionosphere is the abrupt appearance of metal-atomic ions near 82 km on rocket ascent. These metal ions consist mostly of iron and magnesium, and usually exhibit a layer about 5 or more kilometers thick with a peak near 93 km. Whenever metal ion layers are detected at higher altitudes, the thickness of the layers is usually less than 2 km. On the certification rocket, the metal ion concentrations represented a maximum of only about 10 percent of the total ionization near 93 km.

Also, a consistent feature of the lower ionosphere is the ledge of nitric oxide ions near 82 km where NO^+ rises steeply in density becoming the major ion. O_2^+ follows NO^+ and exceeds the NO^+ density above 95 km. In Brazil, we found O_2^+ to be much more abundant between 80 and 90 km than we found in our other daytime measurement at Eglin AFB. This may be because of the smaller solar zenith angle ($\sim 20^o$) in Brazil as compared with the solar angle of 49^o for our earlier measurement at Eglin, resulting in a deeper penetration of solar radiation (that is, Lyman β) which can ionize O_2. Recently, it was pointed out that the

ionization of metastable $O_2(^1\Delta)$ may be equally if not of dominating importance to account for the increased O_2^+ at these low altitudes (Hunten and McElroy, 1968).

The D-4 results plotted in Figure 2 are believed to be displaced about 1 km too high. This rocket was fired when the sun was 80 percent obscured and the results are similar to those of the certification rocket (at least within the discussed excursions), except that an additional metal ion layer composed mostly of magnesium and iron was measured near 105 km. Nothing can be said at this time of the effects of this metal ion layer on the total density profile, because the data from the total charged particle detectors on D-4 were modulated near 105 km.

During totality rocket D-11 reached an apogee of only 95 km so that the upper metal-ion layer could not be measured. However, from a Nike Apache rocket at totality, Mechtley et al. (1969) detected an Es layer at 104.2 km which protruded 50 percent above his smooth electron density profile. In addition, J. C. Ulwick (private communication) found a 20 percent enhancement in his total density profile near the altitude of the metal-ion layer after totality at 80 percent obscuration on rocket D-13. This points out that the metal-ion layer became most prominent in the total density profiles near totality when both molecular ions (NO^+ and O_2^+) decayed to their minimum values. It was expected that if there were no changes in transport processes, the metal atomic ions would show little or no effects due to the solar eclipse because their lifetimes are much longer than the molecular ions and the period of the solar eclipse. The rough results bear out this expectation.

A rough estimate of the change in total density during the eclipse can be made using the mass spectrometer data, by assuming either the iron ion content or the magnesium ion content at 93 km did not change from 5 November and during the eclipse on 12 November. Then, normalizing the 30^+ and 32^+ currents at 93 km to the 56^+ current for the three flights and taking the sum of the normalized 30^+ and 32^+ currents as proportional to density, we find the change in density at 93 km is in the ratio certification: D-4: D-11 = 2.4:1.6:1, or the density at totality is decreased by a factor of 2.4 from normal. Performing the same calculation, assuming the magnesium ion concentration is constant, we obtain for the same ratio 1.8:1.4:1. It is stressed that these are only rough estimates. In comparison, Mechtly et al. (1969) found that the density decrease at totality is uniform above 90 km, and about a factor of three down from the normal daytime ionosphere.

It was also found that the NO^+/O_2^+ ratio increased from 1.1 on the certification rocket to about 1.7 at totality near 93 km. This is understandable qualitatively by considering the basic processes. Simply, in addition to dissociative recombination with electrons, O_2^+ can either charge transfer with neutral nitric oxide or charge rearrange with atomic nitrogen to form and maintain NO^+.

It is difficult at this time to determine what changes occurred in the water cluster ions with accuracy; however, it is estimated that the maximum decay at totality of 37^{+}, for instance, is probably less than a factor of four near 80 km. Other rocket measurements have been performed showing that the water cluster ions indeed can and do change in density through sunrise, through sunset and from midday to midnight. The combination of the low charged particle density in the D region below 80 km (about 10^{3} per cc) and the short time involved in the solar eclipse should prevent the water cluster ions from undergoing a decay as drastic as the electrons, which mainly attach to form negative ions at these low altitudes.

It is again stressed that these data are not completely reduced or analyzed at this time, and only when this is completed can more definite conclusions be reached.

Acknowledgments

We thank the Defense Atomic Support Agency for supporting this research. We also thank Mr. G. Federico for his excellent efforts both in the laboratory and on the field in the preparation and maintenance of the instruments and supporting systems.

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Mechtley, E.A., Seino, K. and Smith, L.G. (1969) Radio Sci. 4:371.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Cambridge Research Laboratories (CRA) L.G. Hanscom Field Bedford, Massachusetts 01730	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP
3. REPORT TITLE POSITIVE ION COMPOSITION MEASUREMENTS IN THE LOWER IONOSPHERE DURING THE 12 NOVEMBER 1966 SOLAR ECLIPSE	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Scientific. Interim.	
5. AUTHOR(S) (First name, middle initial, last name) Rocco S. Narcisi Alan D. Bailey Louis E. Della Lucca	

6. REPORT DATE April 1970	7a. TOTAL NO. OF PAGES 13	7b. NO. OF REFS 11
8a. CONTRACT OR GRANT NO. DASA b. PROJECT, TASK, WORK UNIT NOS. 6687-01-01 c. DOD ELEMENT 62101F d. DOD SUBELEMENT 681000	9a. ORIGINATOR'S REPORT NUMBER(S) AFCRL-70-0293 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) PSRP No. 416	

10. DISTRIBUTION STATEMENT

1-This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES This research was supported by DASA	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories (CRA) L.G. Hanscom Field Bedford, Massachusetts 01730

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Positive ion composition measurements in the D and E regions were performed on three rocket flights during the 1966 solar eclipse program conducted at Cassino, Brazil. The E region results showed that, at totality, NO^+ and O_2^+ decreased in density while the ratio NO^+/O_2^+ increased. Long-lived meteoric ions appeared to be unaffected during the short period of the eclipse. A submerged layer of meteoric ions became prominent at totality when the molecular ion densities were smallest and produced a sporadic E layer. The D region results indicated that the decay in the water cluster ions at totality was probably less than a factor of four in the vicinity of 80 km. This work represents part of a continuing Air Force program to study lower ionospheric processes which affect communications.

DD FORM 1473 1 NOV 65

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Solar eclipse Positive ions Mass spectrometer measurements D and E regions Sporadic E						

UNCLASSIFIED

Security Classification